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THE BIOLOGY OF DEATH—VII. NATURAL DEATH, PUBLIC HEALTH, AND THE POPULATION PROBLEM[1]

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1. Summary of Results

IN this series of papers I have attempted to review some of the important biological and statistical contributions which have been made to the knowledge of natural death and the duration of life, and to synthesize these scattered results into a coherent unified whole. In the present paper I shall endeavor to summarize in the briefest way the scattered facts which have been passed in review in the series, and to follow a presentation of the general results to which they lead with some discussion of what we may reasonably regard the future as having in store for us, so far as may be judged from our present knowledge of the trend of events.

What are the general results of our review of the general biology of death? In the first place, one perceives that natural death is a relatively new thing which appeared first in evolution when differentiation of cells for particular functions came into existence. Unicellular animals are and always have been immortal. The cells of higher organisms, set apart for reproduction in the course of differentiation during evolution, are immortal. The only requisite conditions to make their potential immortality actual are physico-chemical in nature and are now fairly well understood, particularly as a result of the investigations of Loeb upon artificial parthenogenesis and related phenomena. The essential and important somatic cells of the body, however much differentiated, are also potentially immortal, but the conditions necessary for the actual realization of the potential immortality are, in the nature of the case, as has been shown by the brilliant researches of Leo Loeb, Harrison and Carrel on tissue culture, such as can not be realized so long as these cells are actually in and a part of the higher metazoan body. The reason why this is so, and why in consequence death results in the Metazoa, is that in such organisms the specialization of structure and function necessarily makes the several parts of the body mutually dependent for their life upon each other. If one organ or group breaks down, the balance of the whole is upset and death follows. But the individual cells themselves could go on living indefinitely if they were freed, as they are in cultures, of the necessity of depending upon the proper functioning of other cells for their food, oxygen, etc.

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[1] Paper from the Department of Biometry and Vital Statistics, School of Hygiene and Public Health, Johns Hopkins University, No. 34.

So then we see emerging, as our first general result, the fact that natural death is not a necessary or inevitable consequence of life. It is not an attribute of the cell. It is a by-product of progressive evolution—the price we pay for differentiation and specialization of structure and function.

The first result leads logically to the attachment, in any particular organism such as man, of great importance to the quantitative analysis of the manner in which different parts of the body break down and lead to death. Such an analysis, carefully worked through, demonstrates that this breaking down is not a haphazard process, but a highly orderly one resting upon a fundamental biological basis. The progress of the basic tissue elements of the body along the evolutionary pathway is the factor which determines the time when the organ systems in which they are chiefly involved shall break down. Those organ systems that have evolved farthest away from original primitive conditions are the soundest and most resistant, and wear the longest under the strain of functioning. So then, the second large result is that it is the way potentially immortal cells are put together in mutually dependent organ systems that immediately determines the time relations of the life span.

But it was possible to penetrate more deeply into the problem than this by finding that the duration of life is an inherited character of an individual, passed on from parent to offspring, just as is eye color or hair color, though not with the same degree of precision. This has been proved in a variety of ways, first directly for man (Pearson) and for a lower animal, *Drosophila*, (Hyde, Pearl) by measuring the degree of hereditary transmission of duration of life, and indirectly by showing that the death rate was selective (Pearson, Snow, Bell, Ploetz) and had been since nearly the beginning of recorded history, at least. It is heredity which determines the way the organism is put together—the organization of the parts. And it is when parts break down and the organization is upset that death comes. So the third large result is that heredity is the primary and fundamental determiner of the length of the span of life.

Finally, it is possible to say *probably*, though not as yet definitely because the necessary mass of experimental evidence is still lacking, but will I believe be shortly provided, that environmental circumstances play their part in determining the duration of life largely, if not in principle entirely, by influencing the *rate* at which the vital patrimony is spent. If we live rapidly, like Loeb and Northrop's *Drosophila* at the high temperatures, our lives may be gayer, but they will not be so long. The fact appears to be, though reservation of final judgment is necessary till more returns are in, that heredity determines the amount of capital placed in the vital bank upon which we draw to continue life, and which when all used up spells death, while environment, using the term in the broadest sense to include habits of life as well as physical surroundings, determines the rate at which drafts are presented and cashed. The case seems in principle like what obtains in respect of the duration of life of a man-constructed machine. It is self-evident that if of two automobiles of the same make leaving the factory together new at the same time, one is run at the rate of 1,000 miles per year and the other at the rate of 10,000 miles per year, the useful life of the former is bound to be much longer in time than that of the latter, accidents being excluded in both cases. Again, a very high priced car, well-built of the finest materials, may have a shorter duration of life than the shoddiest tin bone-shaker, provided the annual mileage output of the former is many times that of the latter.

The first three of these conclusions I believe to be as firmly grounded as any of the generalizations of science. The last rests at present upon a much less secure footing. Because it does, it offers an extremely promising field for both statistical and experimental research. We need a wide variety of investigations, like those of Loeb and Northrop and of Slonaker, on the experimental side. On the statistical side, well-conceived and careful studies, by the most refined of modern methods, upon occupational mortality seem likely to yield large returns.

2. Public Health Activities

Fortunately, it is possible to get some light on the environmental side from existing statistical data by considering in a broad general way the results of public-health activities, so-called. Any public-health work, of course, deals and can deal in the present state of public sentiment and enlightenment only with environmental matters. Attempts at social control of the germ-plasm—the innate inherited constitutional make-up—of a people, by eugenic *legislation*, have not been conspicuously successful. And there is a good deal of doubt, having regard to all the factors necessarily involved, whether they have always been even well-conceived. As an animal breeder of some years' experience, I have no doubt whatever that almost any breeder of average intelligence, if given omnipotent control over the activities and destinies of human beings, could in a few generations breed a race of men on the average considerably superior—*by our present standards*—to any race of men now existing in respect of many of his qualities or attributes. But, as a practical person, I am equally sure that nothing of the sort is going to be done by legislative action or any similar delegation of powers. Before any sensible person or society is going to entrust the control of its germ-plasm to science, there will be demanded that science know a great deal more than it now does about the vagaries of germ-plasms and how to control them. Another essential difficulty is one of standards. Suppose it to be granted that our knowledge of genetics was sufficiently ample and profound to make it possible to make a racial germ plasm exactly whatever one pleased; what individual or group of individuals could possibly be trusted to decide what it should be? Doubtless many persons of uplifting tendencies would promptly come forward prepared to undertake such a responsibility. But what of history? If it teaches us anything, it is that social, moral and political standards change, and change radically, with the passing of time. What a group of omnipotent thirteenth century geneticists—all well-meaning, sincere, and, for their time, enlightened individuals—would have thought to be an ideal race of human beings would be very far from what we should so regard to-day. One can not but feel that man's instinctive wariness about experimental interferences with his germ plasm is well-founded.

But because of the altogether more impersonal nature of the case, most men individually and society in general are perfectly willing to let anybody do anything they like in the direction of modifying the environment, or trying to, quite regardless of whether science is able to give any slightest inkling on the basis of ascertained facts as to whether the outcome will be good, bad or indifferent. Hence many kinds of weird activities and propaganda flourish like the proverbial bay tree, and with a singularly unanimous and outspoken manifestation of that unenlightened self-indifference, which is so charming a characteristic of the highest descendants of the anthropoids collectively, we go on paying out large sums of money to the end that they may continue to flourish.

Of all activities looking towards the direct modification of the environment to the benefit of mankind, that group comprised under the terms sanitation, hygiene and public health have by all odds the best case when measured in terms of accomplishment. Man's expectation of life has increased as he has come down through the centuries (cf. Pearson and Macdonell.) A very large part of this improvement must surely be credited to his improved understanding of how to cope with an always more or less inimical environment and assuage its asperities to his greater comfort and well-being. To fail to give this credit would be manifestly absurd.

But it would be equally absurd to attempt to maintain that all decline in the death-rate which has occurred has been due to the efforts of health officials, whether conscious or unconscious. The open-minded student of the natural history of disease knows perfectly well that a large part of the improvement in the rate of mortality can not possibly have been due to any such efforts. To illustrate the point, I have prepared a series of illustrations dealing with conditions in the Registra-

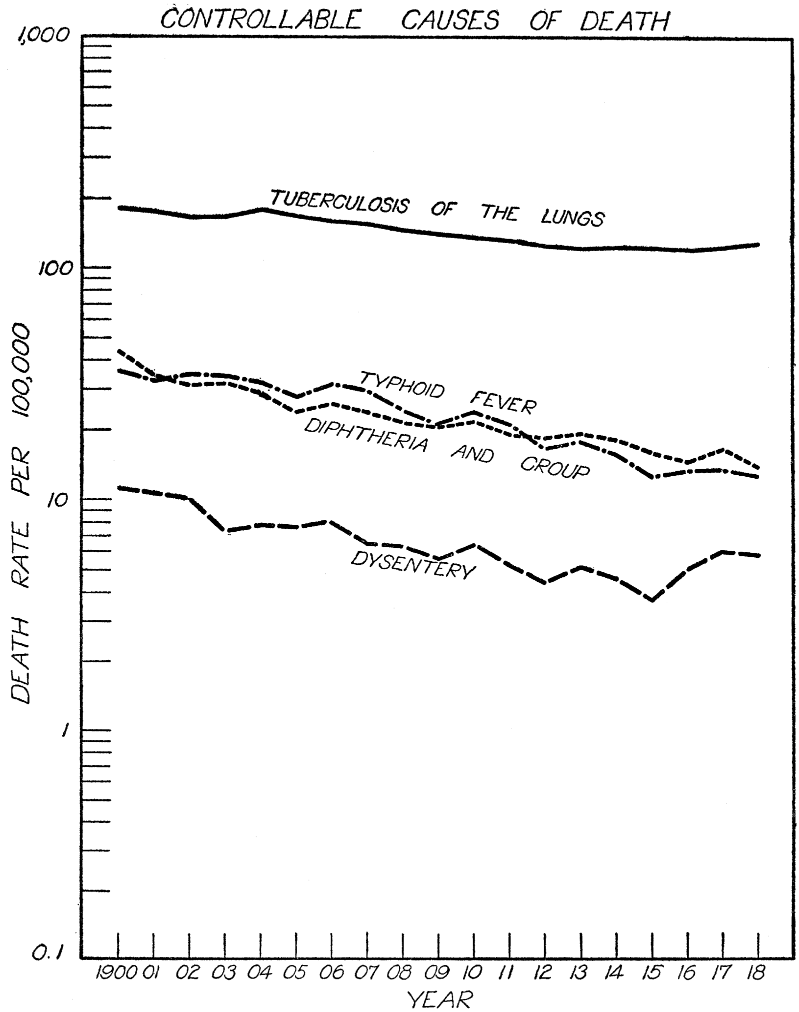

FIG. 1. TREND OF DEATH RATES FOR FOUR CAUSES OF DEATH AGAINST WHICH PUBLIC HEALTH ACTIVITIES HAVE BEEN PARTICULARLY DIRECTED

tion Area of the United States in the immediate past. All these diagrams (Figures 1, 2, and 3) give death rates per 100,000 from various causes of death in the period of 1900-1918, inclusive, both sexes for simplicity being taken together. The lines are all plotted on a logarithmic scale. The result of this method of plotting is that the slope trend of each line is directly comparable with that of any other, no matter what the absolute magnitude of the rates concerned. It is these slopes, measuring improvement in mortality, to which I would especially direct attention.

In Figure 1 are given the trends of the death rates for four diseases against which public health and sanitary activities have been particularly and vigorously directed, with, as we are accustomed to say, most gratifying results. The diseases are:

1. Tuberculosis of the lungs.
2. Typhoid fever.
3. Diphtheria and croup.
4. Dysentery.

We note at once that the death rates from these diseases have all steadily declined in the 19 years under review. But the rate of drop has been slightly unequal. Remembering that the slopes are comparable, wherever the lines may lie, and that an equal slope means a *relatively* equally effective diminution of the mortality of the disease, we note that the death-rate from tuberculosis of the lungs has decreased slightly less than any of the other three. Yet it may fairly be said that so strenuous a warfare, or one engaging in its ranks so many earnest and active workers, has probably never in the history of the world been waged against any disease as that which has been fought in the United States against tuberculosis in the period covered. The rates of decline of the other three diseases are all practically identical.

Figure 2 shows entirely similar trends for four other causes of death—namely:

1. Bronchitis (Acute and Chronic).
2. Paralysis without specified cause.
3. Purulent infection and septicemia.
4. Softening of the brain.

Now it will be granted at once, I think, that public health and sanitation can have had, at the utmost, extremely little if anything to do with the trend of mortality from these four causes of death. For the most part they certainly represent pathological entities far beyond the present reach of the health officer. Yet the outstanding fact is that their rates of mortality have declined and are declining just as did those in the controllable group shown in Figure 1. It is of no moment to say that the four causes of death in the second group are *absolutely* of less importance than some of those in the first group, because what we are here discussing is not relative force of mortality from different causes, but rather the *trend* of mortality from particular causes. The

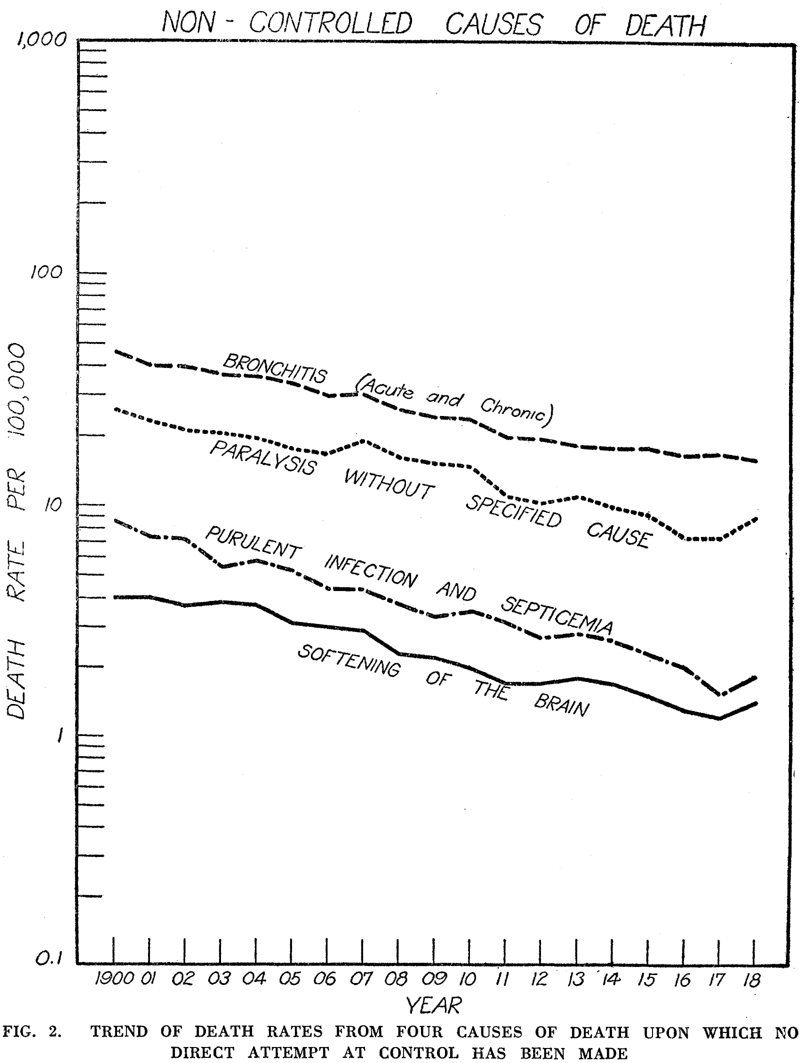

FIG. 2. TREND OF DEATH RATES FROM FOUR CAUSES OF DEATH UPON WHICH NO DIRECT ATTEMPT AT CONTROL HAS BEEN MADE

rate of decline is just as significant, whatever the absolute point from which the curve starts.

It is difficult to carry in the mind an exact impression of the slope of a line, so, in order that a comparison may be made, I have plotted in Figure 3, first, the total rate of mortality from the four controllable causes of death taken together and, second, the total rate of mortality from the four uncontrolled causes taken together. The result is interesting. The two lines were actually nearer together in 1900 than they were in 1918. They have diverged because the mortality from the uncontrolled four has actually decreased faster in the 19 years than has that from the four against which we have been actively fighting.

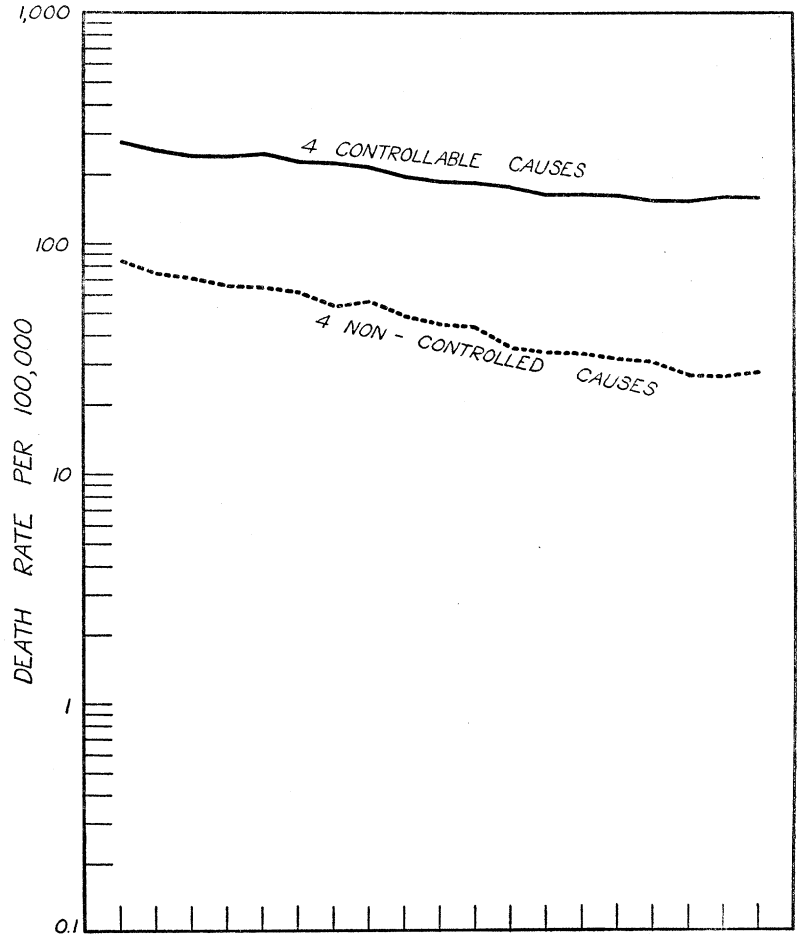

FIG. 3. TREND OF COMBINED DEATH RATE FROM THE FOUR CAUSES SHOWN IN FIGURE 1 AS COMPARED WITH THE FOUR CAUSES SHOWN IN FIGURE 2

The divergence is not great, however. Perhaps we are only justified in saying that the mortality in each of the two groups has notably declined, and at not far from identical rates.

Now the four diseases in this group I chose quite at random from among the causes of death whose rates I knew to be declining, to use as an illustration solely. I could easily pick out eight other causes of death which would illustrate the same point. I do not wish too much stress to be laid upon these examples. If they may serve merely to drive sharply home into the mind that it is only the tyro or the reckless propagandist long ago a stranger to truth who will venture to assert that a declining death-rate in and of itself marks the successful result of human effort, I shall be abundantly satisfied.

There is much in our public health work that is worthy of the highest praise. When based upon a sound foundation of ascertained fact it may, and does, proceed with a step as firm and inexorable as that of Fate itself, to the wiping out of preventable mortality. Some of the work, one regrets to say, has no such foundation, but is built upon the exceedingly shifty sands of ignorance. Having jumped without the slightest real evidence to an unsupported conclusion, the public health propagandist puts into active practice and at great public expense measures which totally lack any scientific validity. I am in great sympathy with the words of the distinguished English pathologist, William Bulloch, who said, in discussing tuberculosis, that he wished "to enter a protest against the wild statements now being made in the lay and medical press, that the whole problem of phthisis was one of infection. Medical history showed that in tuberculosis, as also in the case of other diseases, the most extreme views were taken, not by those who had contributed the actual advancement in knowledge, but by those whose business it was to apply those advancements for the needs of the public. There were a large number of well-ascertained facts which were not entirely explicable on the doctrine that disposition was not an important factor in the genesis of the disease, and that before rigorous measures were applied on a wide scale the actual facts should be ascertained. He did not agree that public health authorities must always 'do something.' This 'doing something' should be put a stop to until there was a reasonable supposition that it was going to achieve its end. He did not wish it to be understood that the tubercle bacillus was not a potent factor. What he did refuse to believe was that it was the only factor. He considered that the disposition, the power of the individual to resist the aggressive inroads of the bacillus, was greater than many people held at the present day."

While this statement of Bulloch's turns upon a controverted issue in the etiology of clinical tuberculosis, namely, as to the relative influence of heredity and environment, the same principle applies to some other phases of public-health work. We shall save a good deal of money and human energy, if we first take the trouble to prove that what we are undertaking to do is in any degree likely to achieve any useful end.

3. The Population Problem

Turning to another phase of the problem, it is apparent that if, as a result of sanitary and hygienic activities and natural evolution, the average duration of human life is greater now than it used to be and is getting greater all the time, then clearly there must be more people on the earth at any time out of a given number born than was formerly the case. It is furthermore plain that if nothing happens to the birth-rate there must eventually be as many persons living upon the habitable parts of the globe as can possibly be supported with food and the other necessities of life. Malthus, whom every one discusses but few take the trouble to read, pointed out many years ago that the problem of population transcends, in its direct importance to the welfare of human beings and forms of social organization, all other problems. Lately we have had a demonstration on a ghastly gigantic scale of the truth of Malthus' contention. For in last analysis it can not be doubted that the underlying cause of the great war through which we have just passed was the ever-growing pressure of population upon subsistence.

Any system or form of activity which tends by however slight an amount to keep more people alive at a given instant of time than would otherwise remain alive adds to the difficulty of the problem of population. We have just seen that this is precisely what our public-health activities aim to do, and in which they succeed in a not inconsiderable degree. But someone will say at once that while it is true that the death-rate is falling more or less generally, still the birth-rate is falling concomitantly, so we need not worry about the population problem. It is evident that if we regard the population problem in terms of world-area, rather than that of any particular country, its degree of immediacy depends upon the ratio of births to deaths in any given time unit. If we examine, as I have recently done, these death-birth ratios for different countries, we find that they give us little hope of any solution of the problem of population by virtue of a supposed general positive correlation between birth rates and death rates.

The relation of birth-rate and death-rate changes to population changes is a simple one and may be put this way. If, neglecting migration as we are justified in doing in the war period and in considering the world problem, in a given time unit the percentage

$$\frac{100 \text{ Deaths}}{\text{Births}}$$

has a value less than 100, it means that the births exceed the deaths and that the population is increasing within the specified time unit. If, on the other hand, the percentage is greater than 100, it means that the deaths are more frequent than the births and that the population is decreasing, again within the specified time unit. The ratio of deaths to births may be conveniently designated as the vital index of a population.

From the raw data of births and deaths, I have calculated the percentage which the deaths were of the births for (a) the 77 non-invaded departments of France; (b) Prussia; (c) Bavaria; and (d) England and Wales, from 1913 to 1920 by years. The results are shown in Table 1.

TABLE 1

Percentage of Deaths to Births

Year	77 non-invaded departments of France	Prussia	Bavaria	England and Wales
1913	97 per cent	....	58 per cent.	57 per cent.
1914	110 “ “	66 per cent.	74 “ “	59 “ “
1915	169 “ “	101 “ “	98 “ “	69 “ “
1916	193 “ “	117 “ “	131 “ “	65 “ “
1917	179 “ “	140 “ “	127 “ “	75 “ “
1918	198 “ “	132* “ “	146 “ “	92 “ “
1919	154 “ “	....	....	73 “ “
1920	....	....	....	42* “ “

* First three-fourths of year only.

The points to be especially noted in Table 1 are:

1. In all the countries here dealt with the death-birth ratio in general rose throughout the war period. This means that the proportion of deaths to births increased so long as the war continued.

2. But in England it never rose to the 100 per cent. mark. In other words, in spite of all the dreadful effects of war, England's net population went on increasing throughout the war.

3. Immediately after the war was over, the death-birth ratio began to drop rapidly in all countries. In England in 1919 it had dropped back from the high figure of 92 per cent. in 1918 to 73 per cent. In France it dropped from the high figure of 198 in 1918 to 154 in 1919, a lower figure than France had shown since 1914. In all the countries the same change is occurring at a rapid pace.

Perhaps the most striking possible illustration of this is the history of the death-birth ratio of the city of Vienna, shown in Figure 4, with data from the United States and England and Wales for comparison. Probably no single large city in the world was so hard hit by the war as Vienna. Yet observe what has happened to its death-birth ratio. Note how sharp is the decline in 1919 after the peak in 1918. In other words, we see how promptly the growth of population tends to regulate itself back towards the normal after even so disturbing an upset as a great war.

In the United States, the death-birth ratio was not affected at all by the war, though it was markedly so by the influenza epidemic. The facts are shown in Figure 4 for the only years for which data are available. The area covered is the United States birth registration area. We see that with the very low death-birth ratio of 56 in 1915, there was no significant change till the influenza year 1918, when the ratio rose to 73 per cent. But in 1919, it promptly dropped back to the normal value of 57.98, almost identical with the 1917 figure of 57.34.

In England and Wales, the provisional figure indicates that 1920

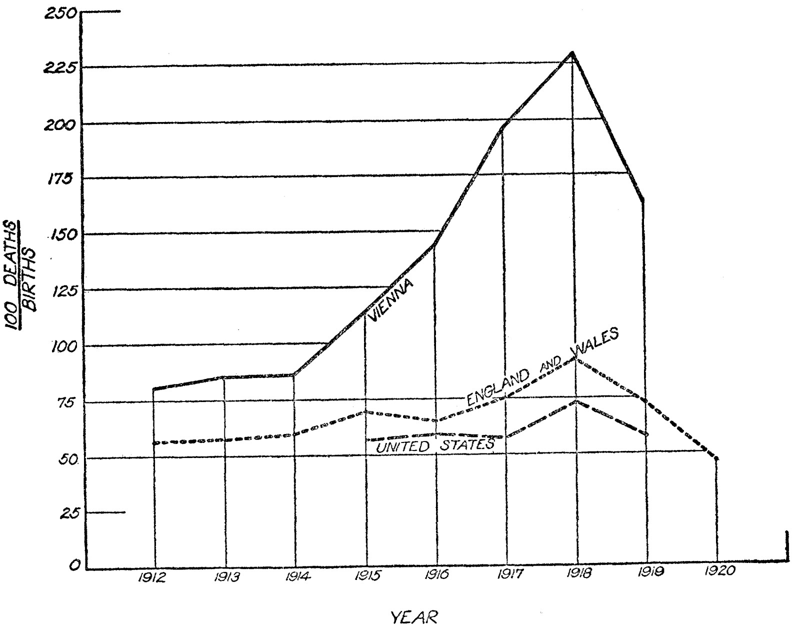

FIG. 4. SHOWING THE CHANGE IN PERCENTAGE WHICH DEATHS WERE OF BIRTHS IN EACH OF THE YEARS 1912 TO 1919 FOR VIENNA (————); 1915 TO 1919 FOR THE UNITED STATES (— — —); AND 1912 TO 1920 FOR ENGLAND AND WALES (......)

will show a lower value for the vital index than that country has had for many years.

So we see that neither the most destructive war the modern world has ever known nor the most destructive epidemic since the Middle Ages serves more than to cause a momentary hesitation in the steady onward march of population growth.

The first thing obviously needed in any scientific approach to the problem of population is a proper mathematical determination and expression of the law of population growth. It has been seen that the most devastating calamities make but a momentary flicker in the steady progress of the curve. Furthermore, population growth is plainly a biological matter. It depends upon, in last analysis, only the basic biological phenomena of fertility and mortality. To the problem of an adequate mathematical expression of the normal growth of populations, my colleague, Dr. Lowell J. Reed, and I have addressed ourselves for some time past. The known data upon which we have to operate are the population counts given by successive censuses. Various attempts have been made in the past to get a mathematical representation of these in order to predict successfully future populations, and to get estimates of the population in inter-censal years. The most noteworthy attempt of this sort is Pritchett's fitting of a parabola of the third order to the United States population from 1790 to 1880 inclusive. This gave a fairly good result over the period, but was obviously purely empirical, expressed no real biological law of change, and in fact failed badly in prediction after 1890.

We have approached the problem from an *a priori* basis, set up a hypothesis as to the biological factors involved, and tested the resulting equation against the facts for a variety of countries. The hypothesis was built up around the following considerations:

1. In any given land area of fixed limits, as by political or natural boundaries, there must necessarily be an upper limit to the number of persons that can be supported on the area. To take an extreme case, it is obvious that not so many as 25,000 persons could possibly stand upon an acre of ground, let alone live on it. So similarly there must be for any area an upper limiting number of persons who can possibly live upon it. In mathematical terms this means that the population curve must have an upper limiting asymptote.

2. At some time in the more or less remote past the population of human beings upon any given land area must have been nearly or quite zero. So the curve must have somewhere a lower limiting asymptote.

3. Between these two levels we assume that the *rate* of growth of the population, that is, the increase in numbers in any given time unit, is proportional to two things, namely:

   a. The absolute amount of growth (or size of population) already attained;

   b. The amount of as yet unutilized, or reserve, means or sources of subsistence still available in the area to support further population.

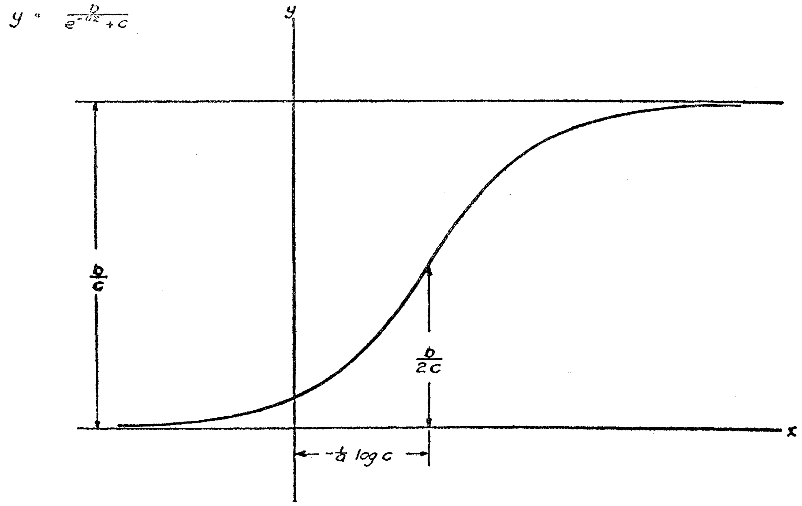

FIG. 5. SHOWING THE THEORETICAL CURVE OF POPULATION GROWTH

These hypotheses lead directly to a curve of the form shown in Figure 5, in which the position of the asymptotes and of the point of inflection, when the population is growing at the most rapid rate, are shown in terms of the constants. It is seen that the whole history of a population as pictured by this curve is something like this: In the early years following the settlement of a country the population growth is slow. Presently it begins to grow faster. After it passes the point where half the available resources of subsistence have been drawn upon and utilized, the rate of growth becomes slower, until finally the maximum population which the area will support is reached.

This theory [2] of population growth makes it possible to predict what the maximum population in a given area will be, and when it will be attained. Furthermore, one can tell exactly when the population is growing at the maximum rate. To test the theory, we have only to fit this theoretical curve to the known facts of population for any country by appropriate mathematical methods. If the hypothesis fits well all the known facts for a variety of countries in different stages of population growth, it may well be regarded as a first approximation to a substantially correct hypothesis and expressive of the biological law according to which population grows. In making this test the statistician has somewhat the same kind of problem that confronts the astronomer calculating the complete orbit of a comet. The astronomer never has more than a relatively few observations of the position of the comet. He has, from Newtonian principles, a general mathematical expression of the laws of motion of heavenly bodies. He must then construct his whole curve from the data given by the few observations. So similarly the statistician has but a relatively few population observations because census taking has been practiced along present lines only a little more than a century. According to the stage in historical development of the country dealt with he may have given an early, a late, or a middle short piece of the population "orbit" or history. From this he must construct on the basis of his general theory of "population orbits" the whole history, past and future, of the population in question.

To demonstrate how successful the population curve shown in Figure 5 is in doing this, three diagrams are presented, each illustrating the growth of the population in a different country. The heavy

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[2] The mathematical hypothesis here dealt with is essentially the same as that of Verhulst put forth in 1844. As Pearl and Reed pointed out in this first paper on the subject it is a special case of a much more general law. A comprehensive general treatment of the problem we are publishing shortly in another place. The generalization in no way alters the conclusions drawn here from a few illustrative examples.

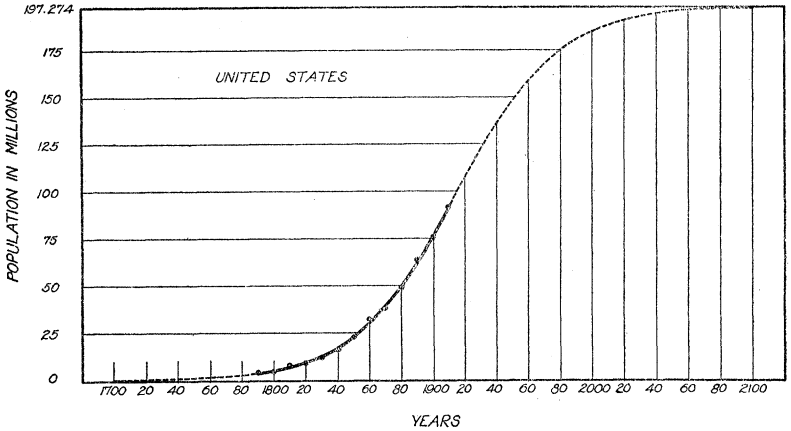

FIG. 6. SHOWING THE CURVE OF GROWTH OF THE POPULATION OF THE UNITED STATES. For further explanation of this and the two following diagrams, see text.

solid portion of each curve shows the region for which census data exist. The lighter broken part of the curve shows the portions outside this observed range. The circles show the actual, known observations. The first curve deals with the population of the United States. Here the observations come from the first part of the curve, when the population was leaving the lower asymptote. First should be noted the extraordinary accuracy with which the mathematical theory describes the known facts. It would be extremely difficult by any process to draw a curve through the observed circles and come nearer to hitting them all than this one does.

Before considering the detailed consequences of this United States curve in relation to the whole population history of the country, let us first examine some curves for other countries where the observed data fell in quite different portions of the "population orbit." Figure 7

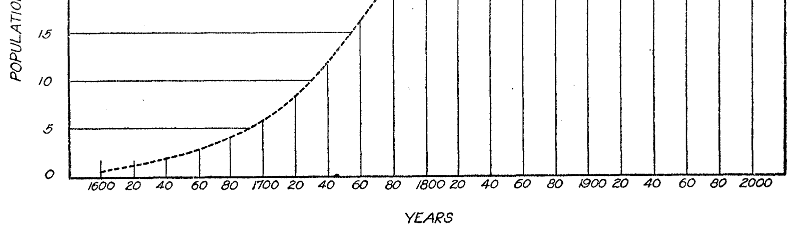

FIG. 7. SHOWING THE CURVE OF GROWTH OF THE POPULATION OF FRANCE

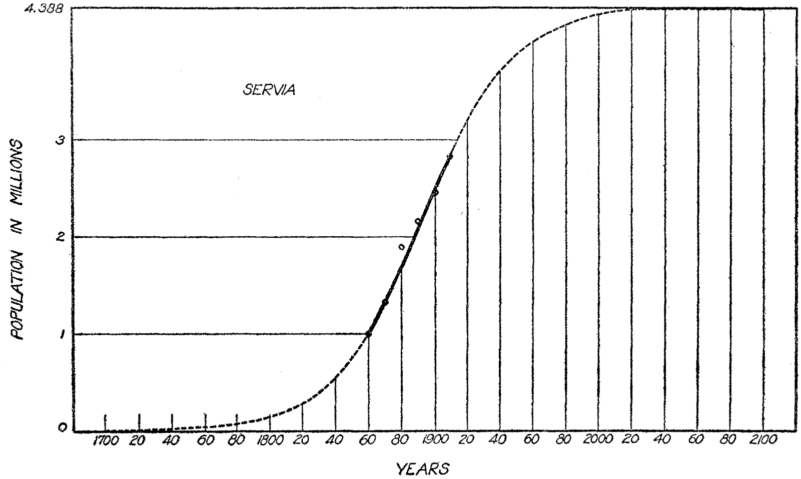

FIG. 8. SHOWING THE CURVE OF GROWTH OF THE POPULATION OF SERBIA

gives the curve for France. Since before the time when definite census records began France has been a rather densely populated country. All the data with which we had to work belong therefore towards the final end of the whole population history curve. The known population data for France and for the United States stand at opposite ends of the whole historical curve. One is an old country whose population is nearing the upper limit; the other a new country whose population started from near the lower asymptote only about a century and a half ago. But it is seen from the diagram that the general theory of population growth fits very perfectly the known facts regarding France's population in the 120 years for which records exist. While there are some irregularities in the observation, due principally to the effects of the Franco-Prussian war, it is plain that on the whole it would be practically impossible to get a better fitting line through the observational circles than the present one.

We have seen that the general theory of population describes with equal accuracy the rate of growth in a young country with rapidly increasing population and an old country where the population is approaching close to the absolute saturation point. Let us now see how it works for a country in an intermediate position in respect of population. Figure 8 shows the population history of Serbia. Here it will be noted at once that the heavy line, which denotes the region of known census data, lies about in the middle of the whole curve. Again the fit of theory to observation is extraordinarily close. No better fit by a general law involving no more than 3 constants could possibly be hoped for.

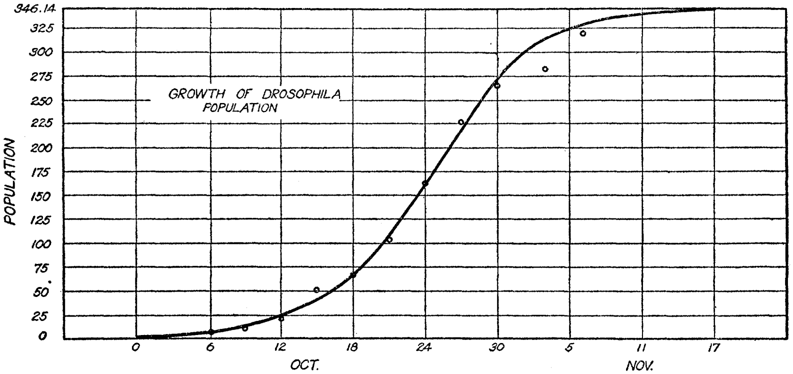

FIG. 9. SHOWING THE GROWTH OF A *DROSOPHILA* POPULATION KEPT UNDER CONTROLLED EXPERIMENTAL CONDITIONS

I think that these three examples, which could be multiplied to include practically every country for which accurate population data exist, furnish a cogent demonstration of the essential soundness and accuracy of this theory of population growth. Indeed, the facts warrant, I believe, our regarding this as a first approximation to the true natural law of population growth. We now have the proper mathematical foundation on which to build sociological discussions of the problem of population.

As a further demonstration of the soundness of this theory of population growth, let attention be directed for a moment to an example of its experimental verification. To a fruit fly (*Drosophila*) in a half pint milk bottle such as is used in experimental work on these organisms, the interior of the bottle represents a definitely limited universe. How does the fly population grow in such a universe? We start a bottle with a male and a female fly, and a small sample, say 10, of their offspring of different ages (larvae and pupae). The results are shown in Figure 9. The circles give the observed population growth, obtained by census counts at 3-day intervals. There can be no doubt that this population has grown in accordance with our law. The two final observations lie below the curve because of the difficulty experienced in this particular experiment of keeping the food supply in good condition after so long a period from the start.

Let us return to the further discussion of the population problem of the United States in the light of our curve.

The first question which interests one is this: When did or will the population curve of this country pass the point of inflection and exhibit a progressively diminishing instead of increasing rate of growth? It is easily determined that this point occurred about April 1, 1914, on the assumption that our present numerical values reliably represent the law of population growth in this country. In other words, so far as we may rely upon present numerical values, the United States has already passed its period of most rapid population growth, unless there comes into play some factor not now known and which has never operated during the past history of the country to make the rate of growth more rapid. The latter contingency appears improbable. The 1920 census confirms the result, indicated by the curve, that the period of most rapid population growth was passed somewhere in the last decade. The population at the point of inflection works out to have been 98,637,000, which was in fact about the population of the country in 1914.

The upper asymptote given by our equation has the value 197,274,000 roughly. This means that the maximum population which continental United States, as now areally limited, will have will be roughly twice the present population. This state of affairs will be reached in about the year 2,100, a little less than two centuries hence. Perhaps it may be thought that the magnitude of this number is not sufficiently imposing. It is so easy, and most writers on population have been so prone, to extrapolate population by geometric series or by a parabola or some such purely empirical curve and arrive at stupendous figures, that calm consideration of real probabilities is most difficult to obtain. While we regard the numerical results as only a rough first approximation, it remains a fact that if anyone will soberly think of every city, every village, every town in this country having its present population multiplied by 2, and will further think of twice as many persons on the land in agricultural pursuits, he will be bound, we think, to conclude that the country would be fairly densely populated. It would have about 66 persons per square mile of land area.

It will at once be pointed out that many European countries have a much greater density of population than 66 persons to the square mile, as, for example, Belgium with 673, the Netherlands with 499, etc. But it must not be forgotten that these countries are far from self-supporting in respect of physical means of subsistence. They are economically self-supporting, which is a very different thing, because by their industrial development at home and in their colonies they produce money enough to buy physical means of subsistence from less densely populated portions of the world. We can, of course, do the same thing, provided that by the time our population gets so dense as to make it necessary there still remain portions of the globe where food, clothing material and fuel are produced in excess of the needs of their home populations.

Now 197,000,000 people will require on the basis of our present food habits about 260,000,000 million calories per annum. The United States, during the seven years 1911-1918, produced as an annual average, in the form of human food, *both primary and secondary* (*i. e.*, broadly vegetable and animal), only 137,163,606 million calories per year. So that, unless our food habits radically change, and a man is able to do with less than 3,000 to 3,500 calories per day, or unless our agricultural production *radically* increases, which it appears not likely to do for a variety of reasons which can not be here gone into, it will be necessary when even our modest figure for the asymptotic population is reached to import nearly or quite one-half of the calories necessary for that population. It seems improbable that the population will go on increasing at any very rapid rate after such a condition is reached. East, in what appears to be the most able and penetrating discussion of population of this generation, has shown that the United States has already entered upon the era of diminishing returns in agriculture in this country. Is it at all reasonable to suppose that by the time this country has closely approached the asymptote here indicated, with all the competition for means of subsistence which the already densely populated countries of Europe will then be putting up, there can be found any portion of the globe producing food in excess of its own needs to an extent to make it possible for us to find the calories we shall need to import?

Altogether, we believe it will be the part of wisdom for any one disposed to criticize our asymptotic value of a hundred and ninety-seven and a quarter millions because it is thought too small, to look further into all the relevant facts.

The relation of this already pressing problem of population to the problem of the duration of life is obvious enough. For every point that the death rate is lowered (or, what is the same thing, the average duration of life increased) the problem of population is made more immediate and more difficult unless there is a corresponding decrease in the birth-rate. Is it to be wondered at that most thoughtful students of the problem of population are ardent advocates of birth-control? Or is it remarkable that Major Leonard Darwin, a son of Charles Darwin and president of the Eugenics Education Society in England, should say in a carefully considered memorandum to the new British Ministry of Health: "In the interests of posterity it is most desirable that parents should now limit the size of their families by any means held by them to be right (provided such means are not injurious to health, nor, like abortion, an offence against public morals) to such an extent that the children could be brought up as efficient citizens and without deterioration in the standards of their civilization; and that parents should not limit the size of the family for any other reasons except on account of definite hereditary defects, or to secure an adequate interval between births."

It seems clear that the problem of population can not be completely or finally solved by limitation of the birth-rate, however much this may help to a solution. There are two ways which have been thought of and practiced, by which a nation may attempt to solve *its* problem of population after it has become very pressing and after the effects of internal industrial development and its creation of wealth have been exhausted. These are, respectively, the methods of France and Germany. By consciously controlled methods France endeavored, and on the whole succeeded, in keeping her birth-rate at just such delicate balance with the death-rate as to make the population nearly stationary. Then any industrial developments simply operated to raise the standard of living of those fortunate enough to be born. France's condition, social, economic and political, in 1914 represented, I think, the results of about the maximum efficiency of what may be called the birth-control method of meeting the problem of population.

Germany deliberately chose the other plan of meeting the problem of population. In fewest words, the scheme was, when your own population pressed too hard upon subsistence, and you had fully liquidated the industrial development asset, to go out and conquer some one, preferably a people operating under the birth-control population plan, and forcibly take his land for your people. To facilitate this operation a high birth-rate is made a matter of sustained propaganda and in every other possible way encouraged. An abundance of cannon fodder is essential to the success of the scheme.

Now the morals of the two plans are not at issue here. Both are regarded, by many people, on different grounds to be sure, as highly immoral. Here we are concerned only with actualities. There can be no doubt that in general and in the long run the bandit plan is bound to win over the birth-control plan if the issue is joined between the two and *only* the two, if its resolution is purely military in character, and if there is no international police force of a magnitude and courage adequate to cope with bandit and otherwise criminal nations. As between two nations, allowed free rein to "fight it out" by themselves without help or hindrance, the decisive element is a mathematically demonstrable one. A stationary population where birth-rate and death-rate are made to balance is necessarily a population with a relative excess of persons in the higher age groups, not of much use as fighters, and a relative deficiency of persons in the lower age groups where the best fighters are. On the contrary, a people with a high birth-rate has a population with an excess of persons in the younger age groups.

So long as there are on the earth aggressively minded peoples who from choice deliberately maintain a high birth-rate, no people can afford to put the birth control solution of the population problem into too extensive operation until such time as the common-sense of mankind decides that peace is in fact a more desirable state of society than war and implements this decision to practical realization through some international equivalent of a police force, which will restrain by force, and plenty of it, the activities of disturbers of the peace. "Disturbance of the peace" is not tolerated in our domestic affairs. It is no more a virtue in international relations. The only effective method which society has yet devised to secure that our home peace shall not be seriously disturbed is that of an adequate police force. There appears no insuperable difficulty in applying the same principle internationally. And any competent economist can easily show that its cost as compared with war would be extremely small. Because something of the sort is not done, one seems bound, however reluctantly, to conclude that nations as nations *prefer* wars and the opportunities for wars to a state of enduring peace. What a long way the average human intellect has still to proceed on its evolutionary pathway!